ON tHE PROBLEM OF CALCULATION OF WATER RESOURcES of sMALL LOW-MOUNTAIN RIVERS

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ABSTRACT-- *In the article preliminary and basic results on calculation of hydrological characteristics of small low-mountain rivers of Uzbekistan for the purpose of calculation of their water resources are presented.*

Key words-- *discharge, flow formation, small low-mountain rivers, hydrological regime, statistic characteristics, coefficients of variation, relative root-mean-square errors.*

I. INTRODUCTION

The work presents the results of calculation of hydrological characteristics obtained for small low-mountain rivers with the long observation series, as only for such rivers it is possible to estimate the water regime characteristics with confidence.

The conditions of the flow formation and hydrological regime of small rivers of low-mountain areas are peculiar and rather complicated for investigation. As for the big and mean-size rivers it is enough to know climatic factors of the flow, which, according to data of many scientists [7, 8, 10, 11, 27, 29], are determined by the elevation of the location. These factors are not enough for the estimation of small low-mountain rivers flow. First of all, the range of the mean elevation of these basins varies within narrow limits from 1,4 to 2,0 km in Syrdarya river basin and from 1,1 to 2,3 km in Amudarya river basin. Besides, as it was noted in the works of many scientists [8, 27, 29], the regularities obtained for big rivers can not be applied to the small rivers as their flow depends on the local non-climatic factors significantly. The effect of the local factors on the river flow is noted by many scientists. These factors are such as geological-and-soil structure of the catchment areas, discrepancy of the borders of surface and underground catchment areas, etc. [7, 8, 10, 11, 27, 29]. Thus, R.M.Masharapov [13] points out that such factors as geological structure of the basin, relief, soil and vegetation cover, size and configuration of the catchment area, density of the river network, etc. influence the flow of the small rivers.

II. PRELIMINARY RESULTS

In this work the actual data are checked for representativeness of the series, synchronism of the river flow variations within hydrological regions and availability of cycles in the fluctuations of water availability of the investigated rivers for getting the reliable hydrological characteristics.

On the base of collected data we estimated the representativeness of the actual series of observations of the

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annual flow values. As it is known, the representativeness of hydrological observation series is determined by the relative root-mean-square error of the mean value of the series [7, 12, 23, 24] which is estimated with the formula:

$$\sigma_n = \pm \frac{100 * C_v}{\sqrt{n}} \%, \quad (1)$$

where C_v – coefficient of variation of the series for n years of observations. The results of calculations are presented in table 1.

The period of observations which meets the notion of representativeness is considered as sufficient one for hydrological calculations. The data providing calculations of the mean values of hydrological characteristics within the admissible errors are attributed to such period. This error (□ n) should not exceed 5 - 10 % for the mean long-term annual flow.

V.L. Schults [137] had found out for the big rivers of Central Asia that for any 25-year period within the period of 1911 - 1960 the flow value differs from the mean long-term value not more than to ± 5%. However, when analyzing the results of calculations presented in table 1, it can be concluded that in this regard, the small low-mountain rivers differ from the big ones. If their C_v is higher than 0,50 and observation series is less than 30 years, then the relative mean root-square error(σ_n) is more than 10 %. Of 32 studied rivers only for 19 ones (59 %) the observation series meet the criterion ($\sigma_n \leq$ 10 %), and correspondingly, they are representative for calculation of hydrological characteristics.

For assessment of the synchronism of the long-term variations of water availability in the group of the small low-mountain rivers it is possible to make superposed graphs for the fluctuations of the mean annual discharge values or to calculate the correlation matrices.

Table 1: Statistical characteristics of the mean long-term flow of investigated rivers

River – gaging station	$Q_{cp.}$, $m^3 \cdot s^{-1}$	C_v	n, years	σ_n, %
1. Surkhandarya river basin				
1. Guliob – Gazarak	0,170	0,70	24	*14,3*
2. Shargun - Chinar	0,813	0,38	38	6,2
3.Gurufatma - Karany	1,61	0,23	27	4,4
4. Aksu - 1.1 km from the mouth	0,422	0,72	37	*12,2*
5. Khangaronsai - Baisun	0,676	0,55	34	9,4
2. Kashkadarya river basin				
6. Guldara - Guldara	0,189	0,32	19	7,3
7. Lyangar – Urtadara	0,531	0,50	23	*10,4*
3. Rivers of the area of Karatepe and Chakylkalyan ridges				
8. Urgut – Urgut urban settlement	0,435	0,49	44	7,4
9. Amankutan - Amankutan	1,02	0,41	38	6,7
10. Agalyk - Agalyk	1,01	0,57	23	*11,9*
11. Sazagan – Sazagan	0,385	0,45	52	6,2
12. Tegermansai - Sagishman	0,278	1,66	26	*32,5*

4. Rivers of the western part of Zeravshan river basin				
13. Aktepasai - Ocha	0,299	0,94	25	*18,8*
14. Karaagach - Mavlyan	0,259	0,50	29	9,3
15. Maidan - Almaata	0,554	0,63	23	*13,1*
5. Rivers of the northern slope of Turkestan ridge and Nurata				
16.Galdraut – Galdraut	0,123	0,72	28	*13,6*
17.Madgerum – Madgerum	0,250	0,60	29	*11,1*
6. Rivers of Akhangaran river basin				
18.Chetyksai – Mouth	0,095	0,61	11	*18,4*
19.Jiblansai – Jiblan	0,536	0,38	28	7,2
20.Naugarzan – 4,5 km from the mouth	1,05	0,40	12	*11,6*
21.Naugarzan – Turk	1,22	0,72	11	*21,7*
22.Abdjasai – Abdjaz	0,641	0,43	31	7,8
23.Shaugazsai – Karatash	0,473	0,50	57	6,6
7. Rivers of Chirchik river basin				
24.Yangikurgan – Yangikurgan	0,697	0,36	43	5,5
25.Nauvalisai – Sidjak	3,78	033	44	5,0
26.Chimgansai – Chimgan	0,302	0,36	41	5,6
27.Karankulsai – Karankul	0,137	0,65	28	*10,1*
28.Galvasai – Galvasai	0,460	0,43	41	8,3
29.Aktashsai – Aktash	0,393	0,38	61	4,9
30.Parkentsai – Sumcha	1,76	0,34	20	7,6
31.Altynbelsai – Kyrgyz	0,387	0,38	38	6,2
32.Parkentsai – Kyrgyz	0,727	0,41	38	6,7

Note: Mean values of Q_{cp}, coefficients of variation C_v and relative root-mean-square errors (σ_n).

We have chosen the second option [8, 18, 31, 32, 33]. In hydrological calculations such correlation is considered as rather reliable one when the values of correlation coefficient are ≥ 0,70. Correlation matrices for all 32 studies small low-mountain rivers, grouped by the regions, are given in table 2. Symbol “ – “ in the table means the absence of coinciding observation periods at the gaging stations.

Table 2: Correlation matrices of the annual flow of the small low-mountain rivers

1. Surkhandarya river basin

Rivers	1	2	3	4	5
1. Guliob	1,000	0,935	0,633	0,715	0,821
2. Shargun		1,000	0,598	0,224	0,724
3. Gurufatma			1,000	0,140	0,436
4. Aksu				1,000	0,240
5. Khangaransai					1,000

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2. Kashkadarya river basin

Rivers	1	2
1. Guldara	1,000	0,580
2. Lyangar		1,000

3. Area of Karatepe and Chakylkalyan ridges

Rivers	1	2	3	4	5
1. Urgut	1,000	0,922	-	0,820	0,753
2. Amankutan		1,000	0,458	0,720	0,370
3. Agalyk			1,000	0,419	-
4. Sazagan				1,000	0,737
5. Tegerman					1,000

4. Western part of Zeravshan river basin

Rivers	1	2	3
1. Aktepasai	1,000	0,832	-
2. Karaagach		1,000	0,866
3. Maidan			1,000

5. Northern slopes of Turkestan ridge and Nurata

Rivers	1	2
1. Galdraut	1,000	0,726
2. Madgerum		1,000

6. Akhangaran river basin

Rivers	1	2	3	4	5	6	7
1. Kyzylcha	1,000	0,974	0,723	0,883	0,971	0,753	0,735
2. Chetyksai		1,000	-	0,984	0,990	-	0,856
3. Jiblan			1,000	-		0,698	0,714
4. Naugarzan - 4,5 km from the mouth				1,000	0,947	-	0,966
5. Naugarzan - Turk					1,000	-	0,773
6. Abdjaz						1,000	0,747
7. Shaugaz							1,000

7. Chirchik river basin

Rivers	1	2	3	4	5	6	7	8	9
1. Yangikurgan	1,000	0,666	0,852	0,783	0,744	0,671	0,733	0,961	0,810
2. Nauvalisai		1,000	0,550	0,908	0,681	0,852	0,717	0,864	0,765
3. Chimgan			1,000	0,825	0,762	0,659	0,650	0,956	0,826

4. Karankul				1,000	0,176	0,921	-	0,702	0,806
5. Galvasai					1,000	0,713	0,796	0,796	0,713
6. Aktashsai						1,000	0,848	0,749	0,805
7. Parkent - 2							1,000	-	-
8. Altynbel								1,000	0,896
9. Parkent									1,000

From the matrices the conclusion about practical synchronism of the trend of fluctuations of the mean annual discharge values in all river groups of Syrdarya basin can be made. Nauvalisai, Yangikurgan and Chimgan rivers in Chirchik river basin are the exceptive ones. To a certain extent, it is explained by certain distinction in exposition of catchments, as with the rivers of similar exposition the values of their correlation coefficients are higher than 0,70.

In Amudarya river basin the synchronism of fluctuations of the mean annual discharge values is observed for the rivers attributed to the group of the western part of Zeravshan river basin. In other groups there are rivers which drop out from the general series. In the river group of Surkhandarya river basin these are Gurufatma and Aksu rivers. In Kashkadarya river basin correlation coefficient between two small rivers is 0,58. In the river group belonging to the area of Karatepe and Chakylkalyan ridges, Amankutan and Agalyk rivers are distinguished. This can be explained by differences in lithologic structure of the basins [19, 20], different exposition of catchments, and also by possible noncoincidence of borders of the surface and underground watersheds, non-registered water intakes in the small populated areas.

As it was pointed out above, the representativeness of hydrological data series is determined by the mean root-square error of the mean value of the series which shows its difference from the flow norm. Consequently, the representativeness depends on the period of duration of observation series and on coefficient of variation, i. e. on the degree of inclusion of the most high-water and low-water years observed on the investigated territory and full water content cycle to the available flow observation series. Water content cycles can be determined by differential integral curves [3, 7, 27, 28]. When constructing these curves it is convenient to express flow in the module coefficients. For comparison of the long-term flow fluctuations over the territory the curve ordinates are usually normalized by C_v, using the following relationship:

$$\frac{\sum (k_I - 1)}{C_V}, \qquad (2)$$

where $k_i = \frac{Q_i}{Q_{cpi}}$.

If difference $\sum(\kappa_i - 1) - \sum(\kappa_{i-1} - 1)$ is less than zero, then $T_i - T_{i-1}$ period is to be low-water one, and if it is higher – then it is considered as high-water period. When the difference equals to zero, then the period can be taken as the rated one. Superposed graphs of the differential integral curves were plotted for each of 7 groups of rivers.

The analysis of graphs shows that in the majority of river groups the low-water periods are generally recorded in the period of 1970 - 1991, while the high-water periods are mainly observed in 1992 - 2007.

Naturally, there are spans within these periods when the negligible short-time changes towards higher or lower values of water availability take place. It is difficult to differentiate the periods of the low- and high-water with the short observation series, as they are hidden by the shorter flow fluctuations.

The main purposes of this work are the studies of water regime of the small low-mountain rivers, estimation of water resources of low-mountain zone of Uzbekistan and finding out of changes of the flow characteristics. Performing of these tasks is not possible without calculation of the main hydrological characteristics of studied rivers. It is known that three situations are possible in this case:

- calculations with availability of long (more than 25 - 30 years) observation series;
- calculations with insufficient (short series) observations;
- calculations in the case of absence of observation series.

Long observations were carried out only on few small low-mountain rivers. Number of rivers for which short observation series are available is also limited. And for the main array of the small rivers there are no data of flow observations at all.

III. MAIN RESULTS

Calculations of hydrological characteristics for rivers with long observation series

With availability of the long observation series flow calculations are reduced to the graph of theoretical frequency curves for the mean annual discharge values.

Calculations made for the Central Asian rivers by V.L.Schults [29] have shown the absence of correlation (r $\leq$ 0,5) between the water availability values of successive years, and consequently, the possibility of application in calculations of theoretical distribution curves. In hydrological calculations the Pearson's distribution curves of the III[rd] type or binomial distribution curves which are also called as the functions of three-parameter gamma-distribution of Kritsky-Menkel are widely used. In the majority of cases the theoretical probability curves plotted on thir base coincide with the actual ones satisfactory [8, 12, 21, 22, 31, 32, 33].

Parameters of these curves are: mean value of Q_{cp} series, coefficient of variation C_v and coefficient of skewness C_s. Naturally, the parameters calculated with these quantities have regular errors related to nature and depending on the number of observation years. With the increase of the number of observation years the errors are decreased rather fast. The minimum admissible duration of observation period should cover possible long-term fluctuations of water availability within the limits from maximum to minimum values rather comprehensively [1, 2, 14].

Building norms and acts (Karakum main canal) [25] set the minimum duration of the series of continuous hydrometric observations which can be used for calculation of parameters of binomial curve: n = 20 years (for the rivers of Central Asia with $C_v \leq 0,30$ a shorter series is admitted – 15–16 years). With our calculations we concluded that for investigation of the small low-mountain rivers, with $C_v \geq 0,50$, the observation period of 30 and more years (Table 1) can be regarded as sufficient one.

Hydrological characteristics of small low-mountain rivers with long observation series are given in table 3 which is an addition to the table 1.

As it seen from tables 1 and 3, the values of the mean long-term flow for all studied rivers vary from 0,189 $m^3 \cdot s^{-1}$ on Guldara river to 3,78 $m^3 \cdot s^{-1}$ on Naulisai river which is explained by difference in the basins areas, physical-and-geographic and climatic conditions. The values of the flow modules (M, $l \cdot s^{-1} \cdot km^{-2}$) vary from 7,19 $l \cdot s^{-1} \cdot km^{-2}$ on Shaugaz river to 38,0 $l \cdot s^{-1} \cdot km^{-2}$ on Naulisai river which shows the dependence from the basin exposition in relation to movement of moisture- laden air masses. The same is confirmed by the values of the flow modules within the distinguished river groups. The values of the flow layer (h, mm) vary from 227 mm over Shaugaz river up to 1199 mm over Nauvalisai river.

Table 3: Rated characteristics of investigated small low-mountain rivers with long observation series

River – gaging station	M, $l \cdot s^{-1} \cdot km^{-2}$	h, mm/year	C_s	C_s/C_v
1. Surkhandarya river basin				
1. Shargun - Chinar	13,7	432	0,50	1,33
2.Gurufatma - Karany	15,6	492	- 0,47	2,03
3. Khangaronsai - Baisun	12,1	382	1,19	2,17
2. Kashkadarya river basin				
4. Guldara - Guldara	7,75	244	-0,30	0,96
3. Rivers of the area of Karatepe and Chakylkalyan ridges				
5. Urgut – Urgut urban settlement	17,3	546	1,75	3,57
6. Amankutan - Amankutan	17,6	555	0,43	1,05
7. Sazagan – Sazagan	14,4	454	0,71	1,57
4. Rivers of the western part of Zeravshan river basin				
8. Karaagach - Mavlyan	7,46	235	0,96	1,92
5. Rivers of the northern slope of Turkestan ridge and Nurata				
6. Rivers of Akhangaran river basin				
9.Jiblansai – Jiblan	28,1	886	0,11	0,30
10. Abdjazsai – Abdjaz	9,09	287	0,27	0,63
11.Shaugazsai – Karatash	7,19	227	0,96	1,91
7. Rivers of Chirchik river basin				
12.Yangikurgan - Yangikurgan	20,7	653	0,69	1,95
13.Nauvalisai – Sidjak	38,0	1199	0,43	1,32
14.Chimgansai – Chimgan	13,0	410	0,65	1,82
15.Galvasai – Galvasai	8,11	256	0,76	1,75
16.Aktashsai – Aktash	20,4	643	0,49	1,28
17.Parkentsai – Sumcha	22,0	694	0,56	1,65
18.Altynbelsai – Kyrgyz	9,90	312	0,58	1,53
19.Parkentsai – Kyrgyz	18,3	577	1,06	2,63

Relative mean root-square errors of the mean values of observation series do not exceed 10 %, according to the set condition on representativeness of series.

As it is known [4, 5, 7, 8, 9, 11, 12, 23, 26, 27, 29] and as it was noted before, the variability of flow of small low-mountain rivers is higher than that of the big rivers, as the increase of the catchment area causes the decrease of variance of the water reserves in snow cover, the increase of share of underground alimentation, etc. Besides, in the low positioned catchments the share of the rain alimentation which is characterized by high variability comparing with the snow and glacial one becomes greater.

Using the rating characteristics given in table 3, the empirical and theoretical curves for the mean annual flow values were constructed. Empirical probability curves were drawn according to the commonly used scheme [7, 8, 12, 21, 22, 27, 28]:

- hydrological characteristics are rated in descending order;
- module coefficients are calculated $k_i = \frac{Q_I}{Q_{CP}}$;
- the empirical probability is estimated (in %) for each rated value by the formula

$$p = \frac{(m-0,3)}{(n+0,4)} \times 100, \tag{3}$$

where m – is ordinal number of the series member, n – is the length of observation period.

Then the graph to (p) which is the empirical curve of the flow modules distribution is plotted; coordinates of theoretical distribution curves are estimated by C_v and C_s values, from the tables of "Ordinates of the curves of the three-parameter gamma-distribution" [14, 27].

Coincidences of theoretical and empirical probability curves turned to be satisfactory for all rivers. In the coure of their analysis some mismatch between the upper and lower parts of the curves (i.e., with the maximum and minimum flow values) was found. These discrepancies were found before by D.L.Sokolovskii [27] who furthermore, noted that if $C_s < 2C_v$, then theoretical probability curve sometimes crosses abscissa axis in the low end. This means that the values of ordinates beginning from some probability near to 100 %, take negative values which contradicts the physical essence of the phenomenon. Mean annual discharge values with different probability for the studied rivers are given in table 4.

Table 4: Mean annual flow values of the small low-mountain rivers ($m^3 \cdot c^{-1}$) with long observation periods of different probability degree

River	P R O B A B I L I T Y , %									
	0,1	1,0	5,0	10	25	50	75	90	95	99
1. Surkhandarya river basin										
1. Shargun	1,91	1,62	1,36	1,24	1,01	0,79	0,58	0,42	0,33	0,20
2. Gurufatma	2,88	2,50	2,20	2,04	1,80	1,55	1,33	1,16	1,06	0,89
3. Khangaronsai	2,51	1,78	1,31	1,11	0,93	0,60	0,43	0,32	0,27	0,19
2. Kashkadarya river basin										
4. Guldara	0,39	0,33	0,29	0,27	0,23	0,19	0,15	0,12	0,10	0,07
3. Rivers of the area of Karatepe and Chakylkalyan ridges										

5. Urgut	1,79	1,19	0,85	0,71	0,53	0,39	0,29	0,23	0,20	0,15
6. Amankutan	2,45	2,07	1,74	1,57	1,28	0,98	0,71	0,49	0,38	0,22
7. Sazagan	2,32	1,83	1,44	1,25	0,98	0,73	0,52	0,38	0,31	0,20
4. Rivers of the western part of Zeravshan river basin										
8. Karaagach	0,79	0,60	0,47	0,40	0,31	0,22	0,15	0,11	0,08	0,05
6. Rivers of Akhangaran river basin										
9.Jiblan	1,19	1,01	0,85	0,77	0,64	0,50	0,37	0,27	0,21	0,13
10.Abdjaz	1,61	1,35	1,13	1,02	0,83	0,63	0,45	0,31	0,24	0,13
11.Shaugaz	1,56	1,19	0,91	0,79	0,59	0,42	0,28	0,20	0,15	0,09
7. Rivers of Chirchik river basin										
12.Yangikurgan	1,66	1,38	1,14	1,02	0,85	0,68	0,54	0,43	0,38	0,28
13.Nauvalisai	8,16	6,65	5,50	4,94	4,13	3,36	2,72	2,24	1,98	1,56
14.Chimgansai	0,75	0,61	0,50	0,44	0,36	0,29	0,22	0,17	0,15	0,10
15.Galvasai	1,40	11,09	0,86	0,75	0,58	0,43	0,31	0,22	0,18	0,11
16.Aktashsai	0,94	0,78	0,65	0,59	0,48	0,38	0,29	0,22	0,18	0,12
17.Parkent- 2	3,66	3,17	2,73	2,50	2,14	1,74	1,38	1,08	0,92	0,65
18.Altynbelsai	0,96	0,78	0,64	0,57	0,47	0,37	0,29	0,23	0,20	0,14
19.Parkent	2,18	1,64	1,27	1,11	0,88	0,68	0,52	0,41	0,36	0,27

Estimation of the mean long-term river flow with short observation series

As it was noted in the works of many scientists [7, 8, 11, 12, 27, 28, 29], when the actual data do not meet the requirements lodged for their statistical processing, then such observation series are regarded as insufficient. Usually, insufficiency of data is related to the short observation period which does not show the character of the flow fluctuations in time. However, even with relatively long observation period the series may not provide for sufficient reliability in calculation of hydrological characteristics, if the data are subjected to substantial temporal variations.

The amplitude of temporal variations of the flow characteristics is determined with the natural causes, including the degree of the area moistening: the less the mean moistness is, the sharper the flow fluctuations are within the years and seasons, and the longer observation period is needed for calculations.

The period of fow observations is regarded as insufficient if:

- the relative root-mean-square error of the mean value is higher than admissible limits;

- the available observation series does not contain complete cycles of water availability and the most high- or low-water years.

For the proper estimation the observation series are reduced to the long (representative) period. The main method of reduction is

Method of hydrological analogy includes the following:

- selection of another river which is analyzed in hydrological aspect and which is in similar conditions with the river-analog with unstudied physical-and-geographical conditions;

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- in application of hydrological characteristics of the investigated object on the object under investigation with the corrections for the incomplete analogy of physical-and-geographical conditions.

For selection of the river-analogs it is necessary to take into account the following:

- the investigated river and potential river-analog should be as close as possible geographically;
- climatic conditions which determine the formation of river flow should be similar;
- annual flow fluctuations on the compared rivers should be synchronous;
- relief of catchments, soil and hydrogeological conditions in the basins of investigated rivers should not differ too much from each other;
- presence of lakes, marshes, forestation and glaciation of catchments should be close by their relative values, i.e., their influence on annual flow should be almost the same in the investigated basins;
- the catchment areas should not differ from each other more than 10 times for the plain rivers, while in mountains the differences in the mean altitude of catchments should be within 300 m, as usually in this case there is no substantial difference in general flow formation conditions;
- absence of factors which distort the natural river flow significantly;
- the period of joined observations of river flow on the investigated river and river-analog should not be less than 10 years, as this period is enough for manifestation of the common features of their flow formation.

The objective criterion for correctness of selection of the analog point is sufficiently close relationship during the years of one-time observations characterized by correlation coefficient and by relationship between regression coefficient K and its root- mean-square error σ_R, if $r \geq 0,7$ and $K/\sigma_R \geq 2$.

One or several rivers which meet the above mentioned requirements can be taken as analog. Taking into account that the case is related to natural objects, it is not easy to choose the analog.

We have graphed correlation matrices for small low-mountain rivers of Syrdarya and Amudarya river basins which have short observation series in each group of investigated rivers. Using the obtained results we have chosen rivers-analogs and selected the optimum period of reduction.

The rivers-analogs were defined as follows: Shaugazsai r. – Karatash vill. for the small rivers of Akhangaran river basin, Aktashsai r. – Aktash recreation area for the rivers of Chirchik river basin, Sazagan r. – Sazagan vill. for the rivers of Zeravshan river basin, Tupolang r. – Zarchob vill., Sangardak r. – Kinguzar vill., Khalkadjar r. – Bazarjoy vill. for rivers of Surkhandarya river basin. The period of 1951 – 2007 years was taken as reduction period.

Linear constraint equations and deviation of values of the mean long-term flow values by the reduced series from the actual mean long-term values ($\Delta = [(Q_{ср.} – Q_{ср. расч.}) / Q_{ср. расч.}] \cdot 100, \%$) are presented in table 5.

From table 5 it is evident that the tightness of obtained correlations meets the requirements lodged to the selection of analogs. In all cases correlation coefficients are higher than 0,70. In table 5: $Q_{пр.}$ – mean annual discharge value by the reduced series, Q_a – mean annual discharge value of river-analog.

Table 5: Equations and tightness of correlations of the mean annual flows of rivers-analogs and rivers with short observation periods

Studied river	River - analog	Constraint equation	r	Q ср. расч., $m^3 \cdot s^{-1}$	Δ, %
1. Surkhandarya river basin					
1. Guliob	Sangardak	$Q_{пр.} = 0{,}0166\ Q_a - 0{,}1026$	0,75	0.175	+1,49
2. Aksu	Khalkadjar	$Q_{пр.} = 0{,}0912\ Q_a - 0{,}1696$	0,79	0,423	-0,81
2. Kashkadarya river basin					
3.Lyangar	Sazagan	$Q_{пр.} = 1{,}5296\ Q_a - 0{,}1975$	0,85	0,394	-14,4
3. Rivers of the area of Karatepe and Chakylkalyan ridges					
4.Agalyk	Sazagan	$Q_{пр.} = 2{,}6741\ Q_a^{\ 0{,}8324}$	0,81	1,14	-13,7
5.Tegerman	Sazagan	$Q_{пр.} = 2{,}0679\ Q_a - 0{,}4588$	0,73	0,341	+22,8
4. Rivers of the western part of Zeravshan river basin					
6.Aktepasai	Sazagan	$Q_{пр.} = 1{,}3726\ Q_a - 0{,}1574$	0,84	0,374	+22,5
7.Maidan	Sazagan	$Q_{пр.} = 1{,}902\ Q_a - 0{,}1128$	0,75	0,623	+14,8
5. Rivers of the northern slope of Turkestan ridge and Nurata					
8.Galdraut	Aksu	$Q_{пр.} = 0{,}0415\ Q_a - 0{,}0885$	0,81	0,097	- 21,1
9.Madgerum	Sanzar	$Q_{пр.} = 0{,}1486\ Q_a - 0{,}0141$	0,76	0,276	+10,6
6. Rivers of Akhangaran river basin					
10.Chetyksai	Shaugaz	$Q_{пр.} = 0{,}2488\ Q_a - 0{,}004$	0.84	0,116	+23,0
11.Naugarzan. 1	Shaugaz	$Q_{пр.} = 2{,}6201\ Q_a + 0{,}2482$	0,94	1,49	+41,7
12.Naugarzan. 2	Shaugaz	$Q_{пр.} = 3{,}1768\ Q_a + 0{,}0274$	0,75	1,53	+24,8
7. Rivers of Chirchik river basin					
13.Karankul	Aktash	$Q_{пр.} = 0{,}5246\ Q_a - 0{,}0652$	0,92	0,141	+6,4

For reduction of the short observation periods to one period in 12 cases of 13 (92%) the linear relationships between the mean annual discharge values of investigated rivers and of rivers-analogs were used. Only for Agalyk river power function was used.

In table 5 the results of calculations of the mean long-term flow of all rivers with short observation series, i.e. mean long-term resources of these rivers are also presented.

As it is known [29], for the conditions of highlands the easiest way is the method of determination of relationships between flow modules (M) and mean elevations of catchments ($H_{ср}$). V.L.Schults [29] and M.N Bolshakov [4, 5] have developed this method rather definitively in application to Central Asian regions.

They also limited the application of relationship $M = f(H_{ср})$ with catchments the area of which is not less than 100 km^2 and elevation range is not less than 1500 m. As V.L. Shults [29] points out, the weak correlation between the mean long-term flow and the mean elevation for water courses with small catchments and small elevation range is determined by the condition that in the low elevation mountain zones, approximately up to 1800 – 2000 m, the increase of atmospheric precipitation with increase of elevation causes the increase of evaporation, mainly, and not the increase of flow. Besides, the effect of non-climatic factors on the small catchments is demonstrated most significantly.

It is known [4, 5, 9, 29] that in mountain regions there exist local relationships between the flow modules and mean basin elevation. The absence of relationships in several mountain regions is seeming. For these regions the complex orography is typical which determines the local character of relationships and requires more detailed investigation.

Evidently, with the increase of number of observation points the type of relationships and their tightness are subjected to changes. Possibly, the need in definition of the local (more detailed) relationships will arise.

Data obtained by reduced series were used as basis for calculation of the mean annual discharge values of different probability on small low-mountain rivers with short observation periods (table 6).

Table 6: Mean annual discharge values of small low-mountain rivers with short observation periods ($m^3 \cdot s^{-1}$) of different probability by reduced series

River	PROBABILITY, %									
	0,1	1,0	5,0	10	25	50	75	90	95	99
1. Surkhandarya river basin										
1. Guliob	0,80	0,54	0,38	0,31	0,22	0,15	0,10	0,07	0,06	0,04
2. Aksu	2,39	1,45	0,94	0,75	0,53	0,37	0,24	0,17	0,14	0,10
2. Kashkadarya river basin										
3. Lyangar	1,33	1,10	0,88	0,76	0,57	0,35	0,18	0,077	0,04	0,01
3. Rivers of the area of Karatepe and Chakylkalyan ridges										
4. Agalyk	3,71	2,77	2,13	1,84	1,41	1,05	0,76	0,56	0,47	0,33
5. Tegerman	1,66	1,47	1,22	1,02	0,58	0,16	0,02	0,001	0	0
4. Rivers of the western part of Zeravshan river basin										
6. Akteepasai	1,80	1,23	0,86	0,70	0,49	0,32	0,20	0,12	0,09	0,05
7. Maidan	2,07	1,63	1,28	1,10	0,83	0,57	0,36	0,22	0,15	0,07
5. Rivers of the northern slope of Turkestan ridge and Nurata										
8. Galdraut	0,50	0,34	0,23	0,17	0,13	0,08	0,05	0,029	0,02	0,01
9.Madgerum	0,98	0,69	0,51	0,44	0,33	0,25	0,19	0,15	0,13	0,10
6. Rivers of Akhangaran river basin										
10.Chetyksai	0,393	0,30	0,23	0,19	0,15	0,11	0,07	0,05	0,04	0,02
11.Naugarzan.1	4,19	3,32	2,65	2,34	1,85	1,40	1,03	0,76	0,64	0,42
12.Naugarzan.2	5,19	3,96	3,03	2,60	1,97	1,38	0,95	0,64	0,50	0,29
7. Rivers of Chirchik river basin										
13.Karankul	0,54	0,40	0,30	0,25	0,19	0,12	0,08	0,05	0,04	0,02

Method of flow estimation for rivers which were not investigated in hydrological aspect

In hydrological practice it is often needed to calculate the flow of uninvestigated rivers.

In the case of absence of data on the measured discharge values the estimation of the mean long-term flow is made with one of the following methods [7, 8, 12, 21, 22, 23, 27, 28]:

- by the maps of the annual flow isolines;
- by zonal relationships of the annual flow from its determining factors;
- by linear interpolation using reference points;
- by the water balance equation.

First two methods are related to the category of indirect methods based on the investigation of relationships between hydrological characteristics and physical-and-geographic factors defining them and subsequent generalization of obtained relationships or regulations of the flow distribution over the territory in the form of isoline maps or regions and analytical equations. These methods are widely used in hydrological calculations, while two last ones are applied with limitations.

The flow isolines are mapped by data on the mean long-term values. Errors of the maps are within 10–20 %, besides the regions with very complex conditions of flow formations or insufficient degree of hydrological investigations where these errors are higher. For estimation of the small river flow it is necessary to introduce the error depending on the catchment area and geographic zone to the flow values taken from the map.

It is expedient to apply interpolation technique for the plain territory with comprehensive knowledge of its hydrological features, and significant errors can rise with its application to mountain area.

When the flow is calculated by the water balance equations the following components are estimated: precipitation, evaporation, flow and others. In the investigated regions the needed water balance elements are not covered by stationary observations.

Regional relationships between river flow and physical-and-geographic factors defining it are applied for the regions with homogeneous conditions of the flow formations. Often for this purpose the following factors and characteristics are used: area and mean elevation of the catchment, inclination of the catchment slopes and river channel, presence of lakes, marshes and forestation of basin, precipitation and evaporation.

As it is known, that in mountain areas the most important factor is elevation of the location [4, 5, 6, 15, 16, 17, 29, 30]. That is why, we used regional relationships between the flow modules (M) and mean basin elevation for the rivers which were not investigated in hydrological aspect.

The technique for arranging of these relationships ($M = f(H_{cp.})$) for all investigated hydrological regions was generalized as follows:

- sampling of observation series was made at all operating gaging stations;
- analysis of observation series was performed for selection of gaging stations with observation period of more than 10 years;
- correlation matrices were arrayed for all selected gaging stations;
- the analog and reduction period were selected;
- the reconstruction of observation series was performed for selected period;
- the flow modules were calculated by the reduced series;
- the regional relationships $M = f(H_{cp.})$ were arranged.

It is necessary to point out that the relationships $M = f(H_{cp.})$ were arranged for eight regions, as the Northern Fergana and South Fergana hydrological regions were included to this sector, while the regions of Karatepe and Chakylkalyan and of the western part of Zeravshan river basin were united to one region.

Using the obtained relationships M = f(H_{cp}) in each investigated hydrological region it is possible to estimate the values of the mean long-term flow for the uninvestigated rivers. Let's present the results of calculations for separate rivers. Chimgan river – actual flow module is 12,4 $l \cdot s^{-1} \cdot km^{-2}$, while the calculated one is 13,6 $l \cdot s^{-1} \cdot km^{-2}$. Deviation from the actual value is 9,7 %. Abdjaz river – actual flow module is 8,59 $l \cdot s^{-1} \cdot km^{-2}$, while the calculated one is 9,31 $l \cdot s^{-1} \cdot km^{-2}$. Deviation is 8,4 %.

IV. CONCLUSIONS

1. Synchronism of fluctuations of flow of small low-mountain rivers within hydrological regions was investigated. It appeared that in majority of cases they are synchronous.

2. We succeeded to calculate sufficiently accurate and reliable hydrological characteristics of small low-mountain rivers for 19 rivers with long observation series. In each of the selected region 1 - 8 such rivers were found out, which were used further as analogs for reconstruction of flow series for rivers with short observation series.

3. For these 19 rivers the annual discharge values of different probability were calculated.

4. The correlations between the flow values of rivers with the short series and with the flow values of rivers-analogs were defined.

5. Using the estimated relationships it was possible to lengthen the series for 13 rivers with short observation periods. It turned out that there are 1 - 4 of such rivers in the region.

6. Information about measured and reconstructed flow values made it possible to get the relationships between mean (for the basins) flow modules and mean elevation values of the basins.

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